

SPATIALLY RESOLVED STAR FORMATION RELATIONS OF DENSE MOLECULAR GAS IN NGC 1068

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ABSTRACT

The Star Formation (SF) activity in galaxy disks reflects a complex balance between local ‘cloud-scales’ and more global ‘disk-scales’ processes, but it is still unclear the influence of the galactic environment on star formation. This work is focusing on: 1) the analysis of the Kennicutt-Schmidt law ($\Sigma_{\text{SFR}} \sim \Sigma_{\text{gas}}^n$), using high-resolution observations of dense molecular gas and Pa- α to trace the recent star-formation, 2) the study of the influence of the dynamical environment in the Starburst (SB) ring of NGC 1068. We observe how K-S power law changes depending, *first*, on the adopted spatial resolution within the range 50-700 pc, and, *secondly*, on the choice of gas tracer. Furthermore, we find a common critical spatial scale of 300-400 pc, above which correlation is statistically significant. We take into account an alternative prescription for SF relations, which include explicitly the dependence of $\text{SFE}_{\text{dense}}$ with the b parameter ($b \equiv \Sigma_{\text{HCN}}/\sigma^2$), that reflect the dynamical state of the gas, showing two different dynamical environments within SB ring. Our results indicate that galactic dynamics plays a role in driving $\text{SFE}_{\text{dense}}$ variations in NGC1068.

Star Formation Relations: Kennicutt-Schmidt law $\rightarrow \Sigma_{\text{SFR}} \sim \Sigma_{\text{gas}}^n$

(Schmidt 1959, Kennicutt 1998)

1) Data at 'global scales' (kpc scales)

$n \sim 1.4-1.7$ — molecular gas (e.g. CO(1-0))

$n \sim 1$ — dense molecular gas (e.g. HCN(1-0))



This seems to suggest: SFE is roughly constant

Is $\text{SFE}_{\text{dense}}$ constant?

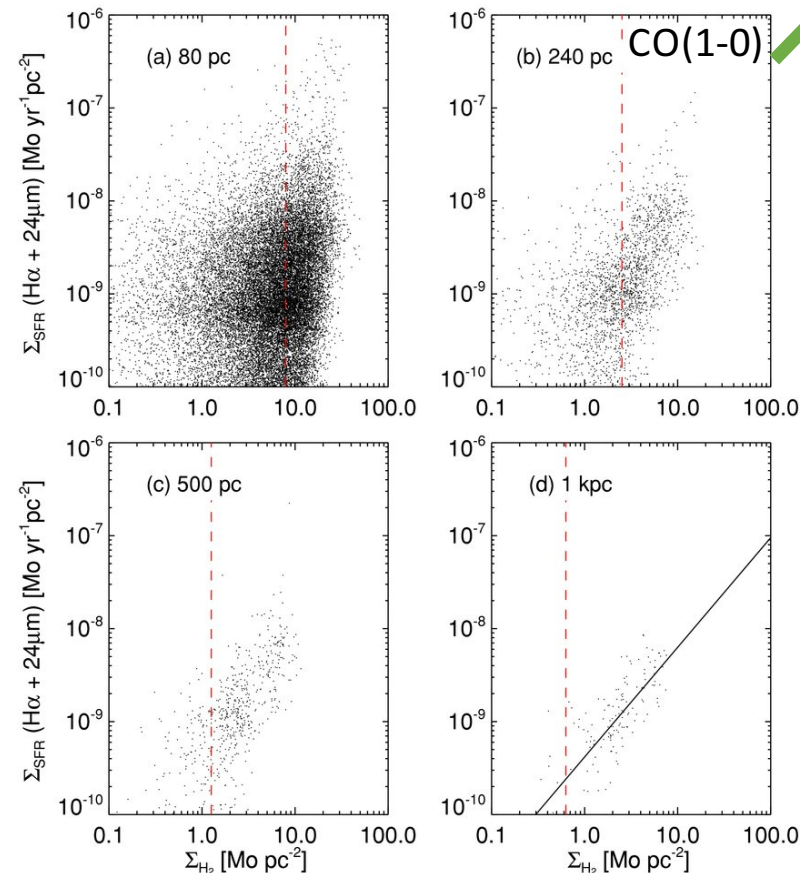


confrontation with models

2) Data at 'cloud scales' (sub-kpc scales)

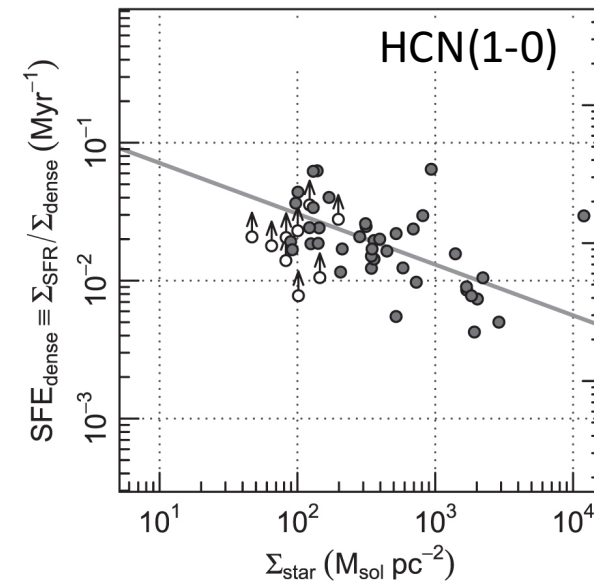
Variations in SF relations

critical scale (Onodera et al. 2010)



Role of dynamical state of clouds

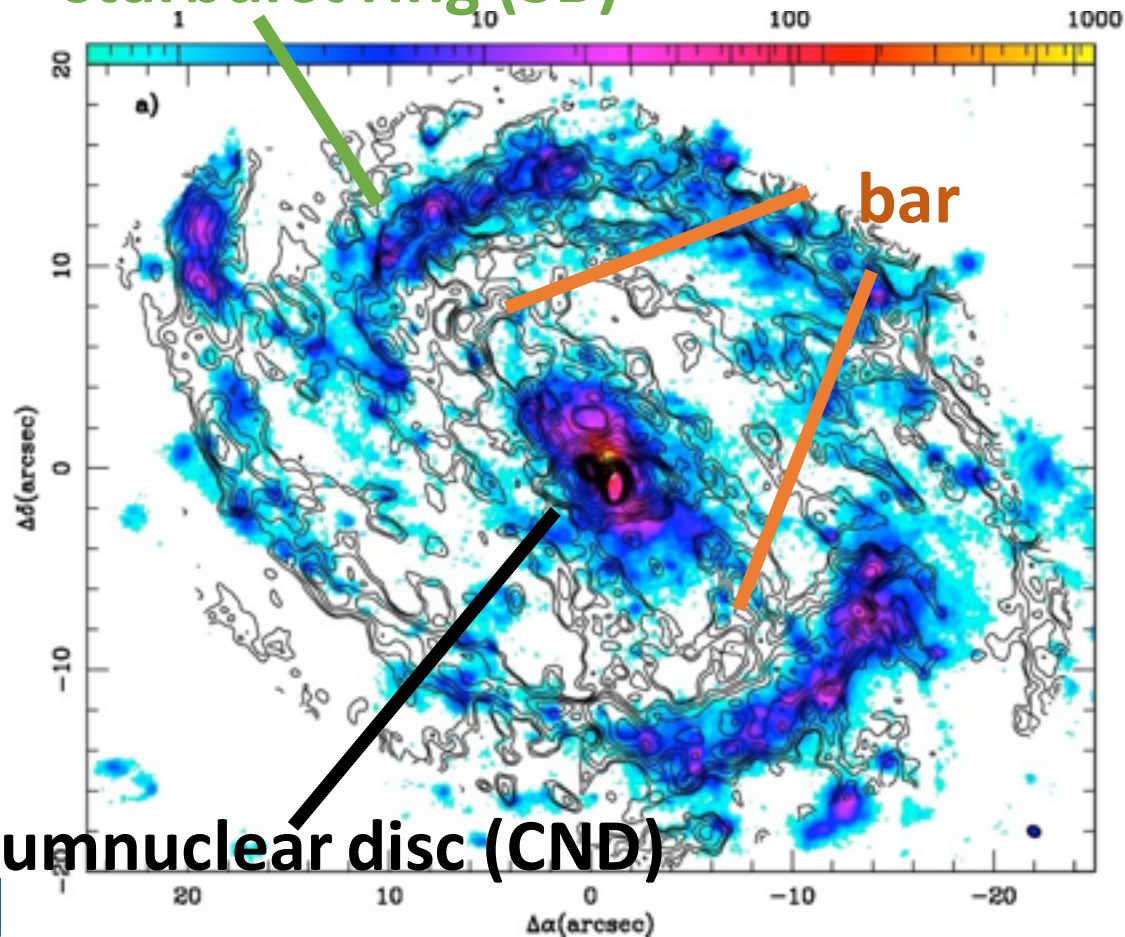
(Usero et al. 2015)



Description of the work

NGC1068: galaxy with SB ($r \sim 1.3 \text{ kpc}$) + AGN barred Seyfert 2 (CND $r \sim 200 \text{ pc}$) at $D = 14 \text{ Mpc}$
($1'' = 70 \text{ pc}$)

starburst ring (SB)



circumnuclear disc (CND)

(García-Burillo 2014)

- OBSERVATIONS:

- Gas tracers

HCN(1-0), HCO+(1-0)

CO(3-2) and continuum emission
at 349 GHz (García-Burillo et al 2014)

ALMA

CO(1-0) (Schinnerer et al 2000)

PdBI

Covering a wide range of densities: $n_{\text{crit}} \approx 10^3 - 10^5 \text{ cm}^{-3}$

- Star formation tracer

Pa- α emission line

HST

We exclude CND in our analysis because the emission in that substructure is contaminated by the AGN

SF relations in SB ring within range 50-700 pc

Results

1)

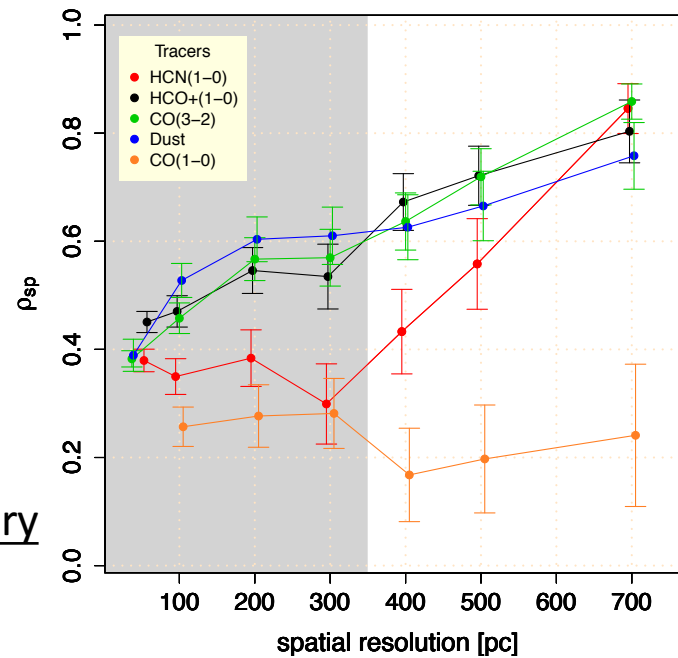
K-S plot:

axis $y - \Sigma_{\text{SFR}}$, axis $x - \Sigma_{\text{gas}}$

Relation correlation $\rightarrow \rho_{\text{sp}}$

We obtain K-S plot for each gas tracer and for each spatial scale

Summary



- For a common spatial resolution, correlation of relations is a factor of two larger for highest density gas tracers

$$\text{e.g. } \rho_{\text{ps}}[\text{HCO}^+(1-0)] \sim 2 \rho_{\text{ps}}[\text{CO}(1-0)]$$

- For all gas tracers, relations are less scattered when equivalent larger apertures are used

- Correlation is statistically significant:

$$\text{p-value} < 1\% \text{ and } \rho_{\text{sp}}, \rho_{\text{ps}} > 0.4$$

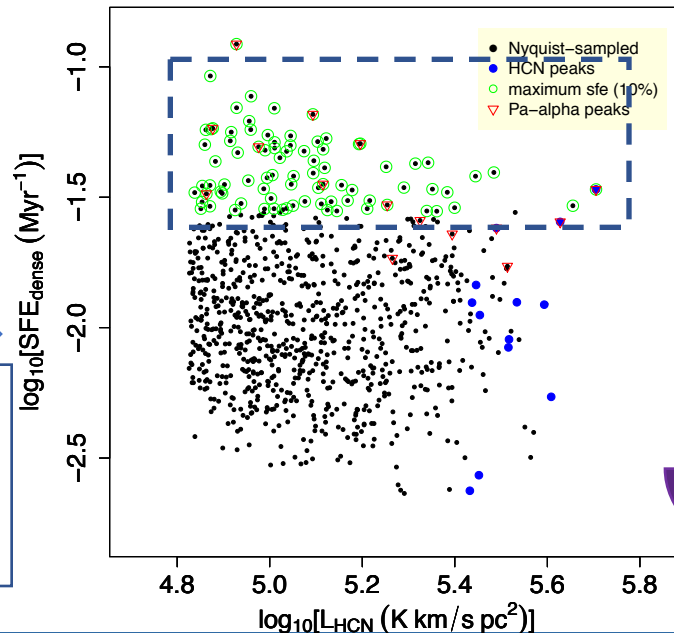
scale $\approx 300\text{-}400$ pc

2) We define:

$$\text{SFE}_{\text{dense}} \equiv \Sigma_{\text{SFR}} / \Sigma_{\text{dense}}$$

What happend inside cloud of points?

We select points:
more efficient (10%),
local maximum of HCN
and Pa- α

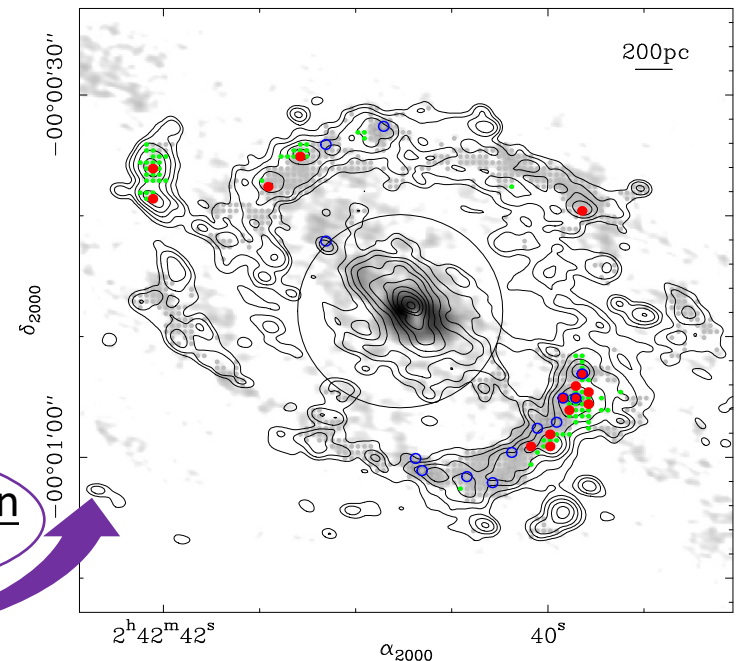


$T_{\text{dep}} \sim 10\text{-}35$ Myr

(U)LIRGs

(García-Burillo et al 2012)

NO random distribution
in SBring



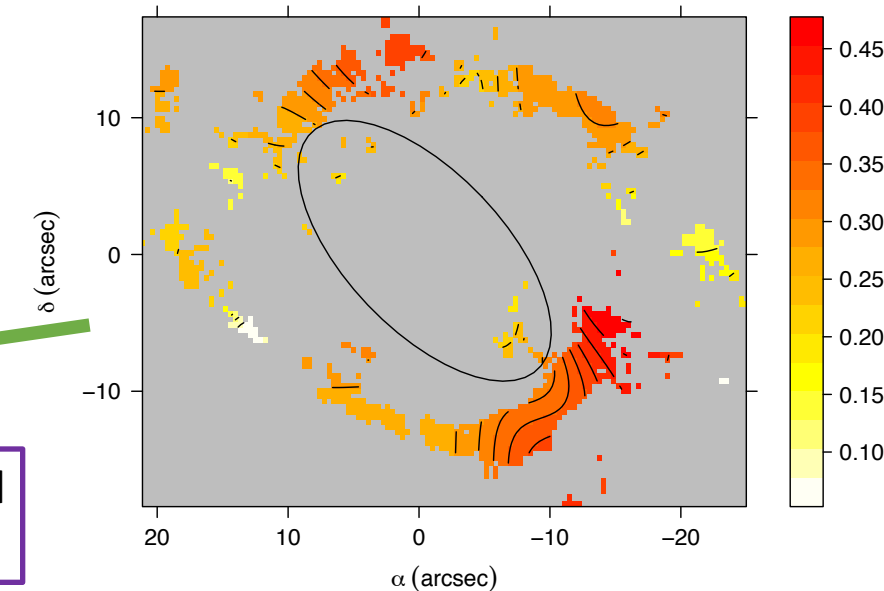
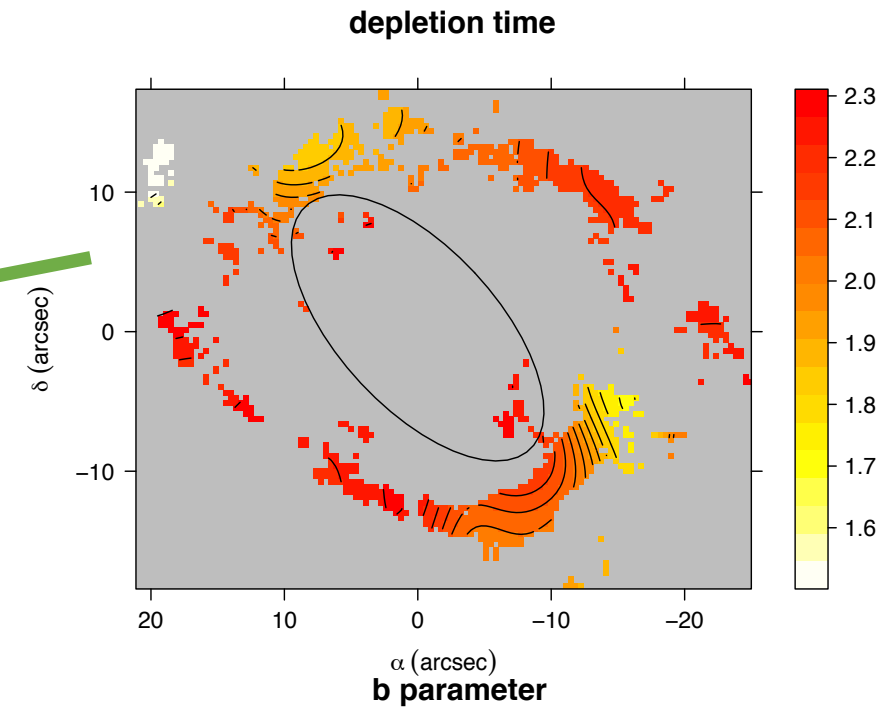
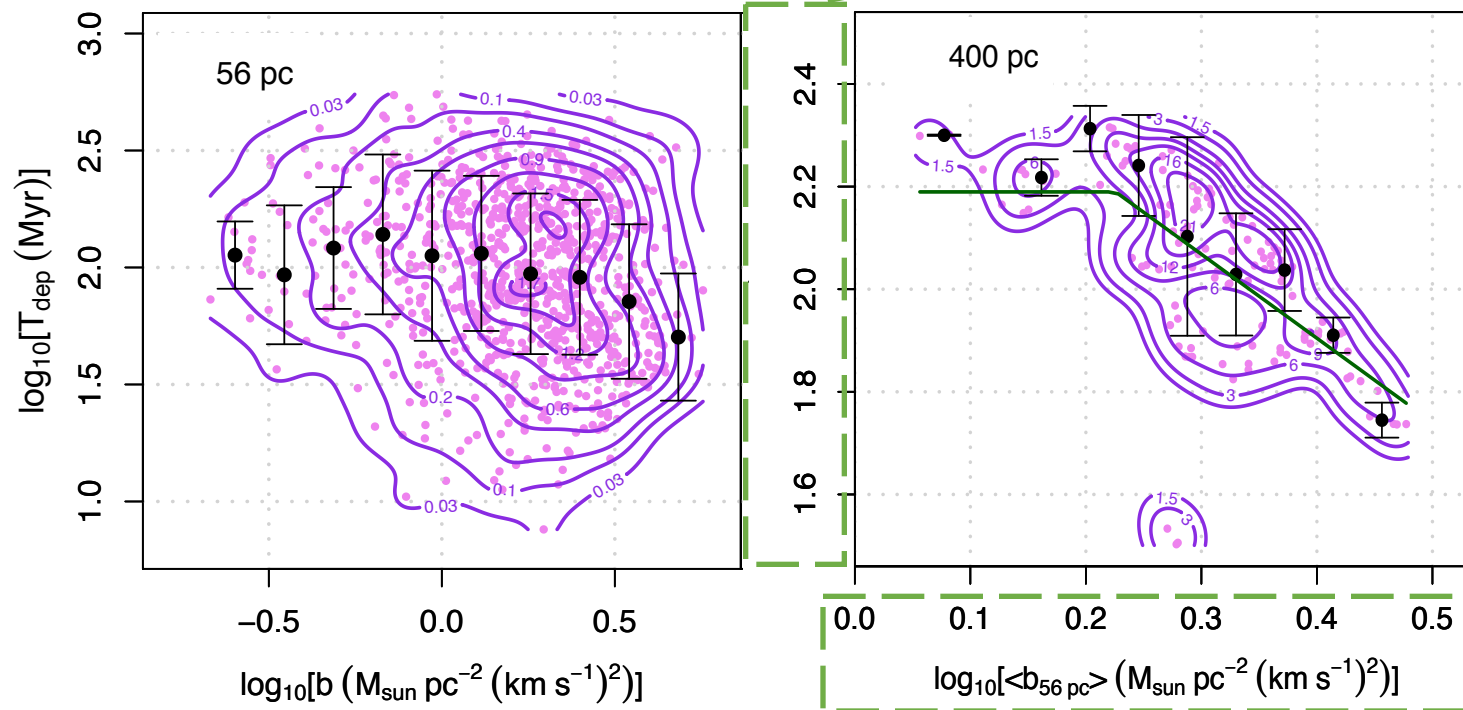
More Results

3) We define:

$$- b \equiv \frac{\Sigma_{\text{HCN}}}{\sigma^2} \propto \alpha_{\text{vir}}^{-1} \approx \frac{UE}{2KE} \rightarrow \text{traces the self-gravity of the gas (+ Intensity-Weighted Averages)}$$

(Leroy et al 2017)

$$- T_{\text{dep}} \equiv \frac{M_{\text{HCN}}}{\text{SFR}} = \text{SFE}_{\text{dense}}^{-1}$$



2 branches in the $\text{SFE}_{\text{dense}}^{-1}$ - b plot corresponding to two different dynamical environments in the SB ring depending on location relative to the bar

Interpretation and impact

- We have studied **star-formation laws in NGC 1068** combining ALMA and HST data
- $\Sigma_{\text{SFR}} - \Sigma_{\text{gas}}$ relation in NGC1068 is less scattered for higher density tracers:
[e.g. $\rho_{\text{ps}}[\text{HCO}^+(1-0)] \sim 2 \rho_{\text{ps}}[\text{CO}(1-0)]$]
- A '**critical scale**' for $\Sigma_{\text{SFR}} - \Sigma_{\text{gas}}$ plot: **300-400 pc**
- Spatial resolution and alternative prescription of SF relations beat 'degeneracy' of $\text{SFE}_{\text{dense}}$
- $\text{SFE}_{\text{dense}}$ correlated with 'boundedness' ($b \equiv \frac{\Sigma_{\text{HCN}}}{\sigma^2}$) of dense gas:
Two branches in $\text{SFE}_{\text{dense}} - b$ plot linked to two different dynamical environments within SB ring
- Our results indicate that galactic dynamics plays key role in driving $\text{SFE}_{\text{dense}}$ variations in NGC1068